INTEGRATED HELMET SYSTEM TESTING FOR A NIGHTFLYING HELICOPTER

Dr. H.–D.V. Böhm and Dr. H. Schreyer

Messerschmitt–Bölkow–Blohm GmbH
Helicopter Division
Deutsche Aerospace
Post Box 80 11 40
8000 München 80, FRG

SUMMARY

A modern integrated helmet system (IHS) consists of a helmet shell, a Helmet Mounted Sight (HMS), two Image Intensifier Tubes (IIT) and two Cathode Ray Tubes (CRT) with an optical system including combiners to present the images binocular. Additional symbology can be superimposed to the CRT– or IIT–image. An IHS is a further development of a Helmet Mounted Display (HMD) to cope with more demanding requirements regarding ergonomics and operability under adverse visual conditions. The HMS can steer a sensor platform with a thermal camera or an air–to–air missile system. The main helicopter (HC) requirements on such a system are:

- o human factors
- o fit of helmet including optimized centre of gravity(CG) and weight
- o optimized day, twilight and night optical modules
- o large exit pupil, good transmission of the optical path and a large adjustment range
- o good geometrical resolution / Modulation Transfer Function (MTF) with a large Field of View (FOV)
- o high focussing range of the IIT and a good S/N ratio below 1 mLux
- o CRT automatic brightness and contrast control with a good readability on day time
- o flight symbology presentation for one or two eyes
- o good static and dynamic HMS–accuracy with a large Head Motion Box (HMB)
- o NBC and Laser protection compatibility

MBB and the German Army Aviation Corps have made last and this year ground and flight trails with an Integrated Helmet and a HMS on a PAH 1 respectively a BK 117 helicopter. The paper will present IHS requirements for HC application and some test results.

1. INTRODUCTION

MBB is presently under contract to the German ministry of defence to update the present PAH 1 (anti–tank helicopter BO 105) and also to develop, in association with Aerospatiale/France, the TIGER second generation anti–tank helicopter (PAH 2). Both HC are expected to be capable of flying and fighting at day/night on similar missions.

The TIGER has installed in the helicopter nose a steerable platform with a 30° by 40° piloting thermal imager (TI). Currently the complete Pilot Visionic System (PVS) has two **monocular** Helmet–Mounted Sight/Displays (HMS/D) for the pilot and copilot cockpit. The monocular HMS/D is under contract by Sextant / VDO. The TI sensor alone can have a great disadvantage during a 24 hour mission. The absolute temperature characteristic or the emissivity of natural materials as a function of a 24 hour period will vary, ref. 1, 2, 3, 4 and 5 p. 93. A thermal zero contrast (wash out effect) during rainfall or a so called **cross–over effect** are observed especially during twilight (morning and evening). Then the foreground is not detectable against the background, so that e.g. pylons can be become very dangerous for the helicopter crew.

Therefore the combination of the two visual aids: image intensifier tubes (IIT) and thermal imagers (TI), which are based on different physical principles, is better suited to fulfil the increased requirements of adverse weather conditions during day and night time. These two visual aids can be combined in an **Integrated Helmet** (IHS) with **binocular** vision (**two CRTs** and **two IITs** on the helmet). The crew can switch between the intensifier tube image and the thermal image nearly without any delay. Additionally flight symbology can be superimposed with the images.

The available HMS–systems work on different physical principles. MBB has tested an electromagnetic AC–system in the FLAB program, ref.1 and during Gun Turret test trials. In 1990 an electromagnetic DC–system and an electro acoustic system were tested for the PAH 2 application, ref. 6.

Two suitable IHSs with a HMS were tested in the MBB visionic lab. In parallel, two PAH 1 helicopters have been equipped with the Racal **RAMS** incl. GEC Avionics **KNIGHT HELM** and with an Elbit **HALO** Night Vision and Mission Management Systems. These are to be used in troop trials at Celle, FRG, to gather experience of operations with state of the art equipment before deciding on the final configuration. The first time a Night Vision System with CRTs flight symbol presentation and IITs in an **IHS KNIGHT HELM** including **see–through capability** were tested on a helicopter (HC). Presently, the PAH 1 system has no TI piloting sensor. Therefore a thermal image evaluation with CRTs was not possible, but a TV image was available in the HC for IHS application.

2. INTEGRATED HELMET SYSTEMS "WITH SECOND SENSOR"

2.1 Review of existing Integrated Helmets with CRTs and IITs

2.1.1 GEC Avionics KNIGHT–HELM

The basic KNIGHT HELM provides NVG operation by IITs and the CRTs generated displays of TI and symbology (FOV 35° circular). This combined IIT/CRT Helmet Display offers a high level of system flexibility and failure survival. The equipment is suited to in–service life, because all the electro–optical parts are protected by the helmet shell. New materials are being used for this helmet shell to retain strength and impact protection in a lighter weight structure. The optical modules are very compact and can be adjusted for interpupillary distance (**IPD**) and can be moved slightly (up/down and fore/aft) with respect to the helmet shell. The see–through capability is mandatory. PAH 1 trail uses **one day/night module** but GEC has now developed a modular concept for IHS. Fig. 1 shows the GEC KNIGHT HELM, ref. 7 and 8. The current status of the IHS is readiness for TIGER development, if go ahead will be decided.

Fig. 1 **Integrated Helmet System KNIGHT HELM from GEC Avionics with IITs and CRTs Displays using flat eyepieces like mini–HUD prisms**

2.1.2 Honeywell MONARC (Monolithic Afocal Relay Combiner)

The basic helmet has a shell which can be fitted with an individual form fit liner. With this good adaptation the helmet provides a comfortable centre of gravity. On both sides of the basic helmet are adapted the optical modules with **biocular** (only one image source but two tubes) CRT displays and **binocular** IITs (FOV 35° circular). The images of these two channels are displayed with a monolithic afocal combiner to the eyes. The see–through vision of the wearer is ensured and the field of regard is slightly obstructed. Each of the turnable combiners is part of the optical module. The optical modules can be adjusted for IPD and may be moved up and down. The MONARC was tested for several days at MBB lab and was flown for several days on PAH 1. Fig. 2 shows the Honeywell MONARC, ref. 4, 5 and 9. The current status of the IHS is readiness for TIGER development, if go ahead will be decided.

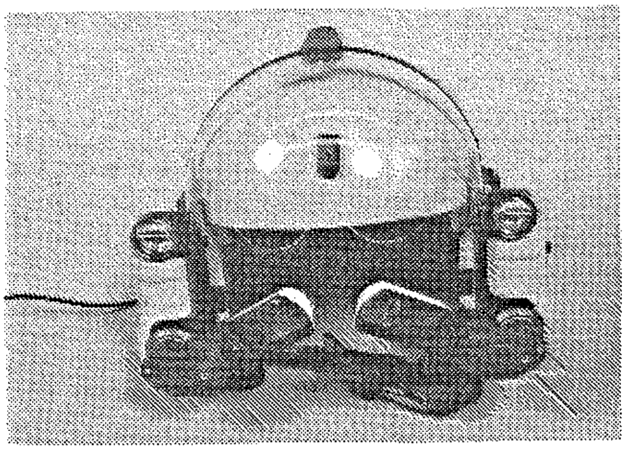


Fig. 2 Integrated Helmet System MONARC from Honeywell with CRTs and IITs Displays using turnable combiners

2.1.3 Kaiser Electronics STRIKE EYE

The basic helmet has a shell which can be fitted with an individual form fit liner. On both sides of the basic helmet the optical modules with biocular (only one image source but two tubes) CRT displays (30° by 40° overlap) and binocular IITs (FOV 30° circular) are adapted in eye position. The images of these two channels are displayed with combiners from above the eyes. The see–through vision of the wearer is ensured. The combiners are retractable and adjustable, see fig. 3 and ref. 4 and 10.

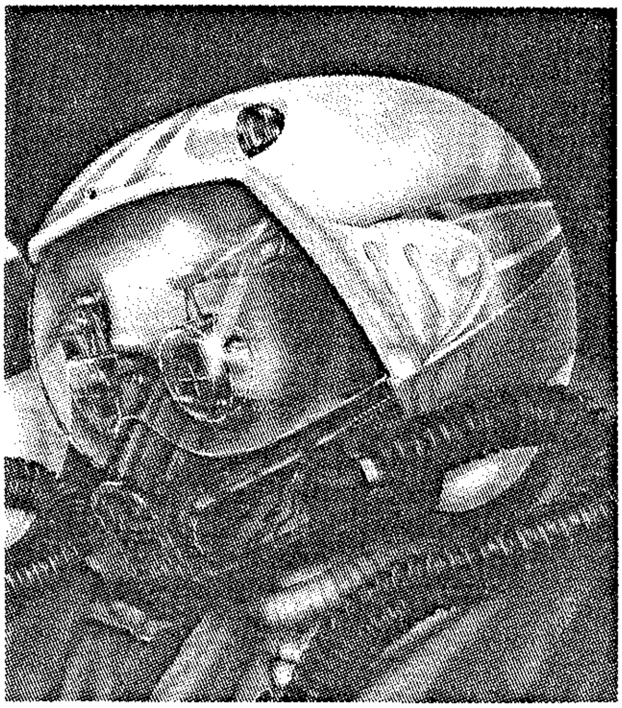


Fig. 3 Integrated Helmet System STRIKE EYE from Kaiser Electronics

2.1.4 Sextant/VDO Helmet Mounted Sight/ Display with Light Intensifiers

The basic helmet is personalized and is generally kept by its wearer. It is a new design, using modern composite materials and optimization techniques. This was necessary to provide adequate mechanical mounting for the Day/Night Module, minimizing the helmet weight. On both sides of the basic helmet the optical modules with biocular (only one image source but two tubes) CRT displays and binocular IITs (FOV 40° circular design) are adapted in eye position. The images of these two channels are displayed with combiners from above the eyes. The see–through vision of the wearer is ensured. The combiners are retractable and adjustable. Since June 1989 a technical exchange took place between Sextant/VDO and Kaiser Electronics mainly in ergonomy field. The current status of the IHS is readiness for TIGER development, if go ahead will be decided, ref. 11 and fig. 4.

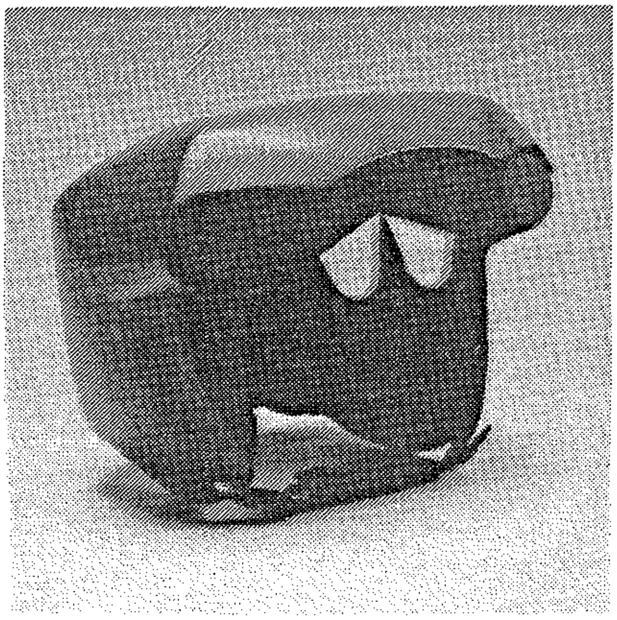


Fig. 4 Integrated Helmet System from Sextant/ VDO

2.2 Mission aspects and optical day / night modules

A Tactical Flight (TF) including Nap of the Earth (NOE) mission will occur approx. 25% of total flight hours and a Night Tactical Flight (NTF) approx. 15% with visual aids, that means with IIT during night or TI during day/night. An IHS improves the safety drastically. If a night flying system with two night sensors uses the IITs on the helmet, then the HMS, the CRTs and TI sensor platform can have a failure without hazardous consequences. The IITs have two battery packs which are independent from the HC power supply. The **reliability** and **flight safety** analyses including a **catastrophic fault/event** improves tremendously.

Symbology projection into one eye or two eyes for day/night application: The IHS KNIGHT HELM incorporates a binocular arrangement with two separate IITs and separate **left** and **right** CRT; thus enabling full flight symbology or outside world scene via a thermal imager to be displayed in the helmet. The technique of presenting information to a pilot in this manner is complex and requires the pilot's eyes and brain to integrate the information displayed, to produce one image and not a double image.

The CRTs of KNIGHT HELM are nominally focussed to be compatible with the IITs, and the optics are designed to cope with a certain latitude in the point of focus of the pilots eyes, i.e. whether he is looking close or distant. When using TI, the IITs should be switched off, and the pilots view one image from two CRT sources. This is a usual technique. When using IITs plus flight symbology the pilot has to integrate one image from four sources; two IITs plus two CRTs. This is complicated by the **focussing** and **convergence** properties of the eye. In any case the magnification of the systems should be 1:1. Certain pilots flying the PAH 1 have had difficulties in focussing upon the flight symbology in the helmet. GEC has made investigation to confirm that the **focal plane** of the two CRTs matches that of the IITs.

Whilst two CRTs are mandatory for night flying with thermal images, two CRTs may not be necessary for night vision with flight symbology. In fact studies have shown that a pilot receiving information from CRT to one eye may not be able to distinguish which eye is receiving the information. Double images of the flight symbology or the scene appear as eye convergence is shifted to fix nearby objects while the collimated symbology is at infinity focus, by definition.

To improve the situation with PAH 1 GEC Avionics implemented a switch to allow the pilots to select manually left CRT, right CRT or both. The results were favourable; the problems associated with image separation and headaches when using flight symbology decreased and the pilots were at liberty to use two CRTs again for TI.

Auto Contrast/Brightness Sensor for CRTs: Pilots have expressed dissatisfaction that the brightness and contrast levels of the flight symbology in the **helmet–CRTs** are only manually adjustable. Under certain ambient light conditions at night, the outside light level is bright, requiring the symbol brightness in the helmet to be increased. But when the pilot then looks into foreground for example, the symbols are **too** bright compared with the night vision scene. To improve this situation GEC Avionics are implementing an auto–contrast control. When auto–contrast is selected, a photo detector assembly mounted on the helmet will increase or decrease the pre set contrast/brightness level dependent upon whether the pilot looks into a bright or dark area. This sensor will **only** affect the symbology displayed by the CRT since the IIT incorporates a separate auto brightness function.

Form Fit Liners should ensure that the helmet is **personalized** to each pilot and provide a comfortable platform for the **Integrated Helmet System** with correct performance, lifetime, compliance and comfort. One of the particular problems GEC Avionics has encountered through the trials is that one helmet liner is not ideally suited to be used in two helmets of different weights, i.e. night vision only helmet and helmet with night vision and CRTs (compare chapter 2.6.). When GEC Avionics supplied the second helmet for evaluation (which contained only night vision without CRTs), there was some criticism by the pilots that the helmet **shell** was smaller and less comfortable than the first helmet supplied. In fact, the two helmets were exactly the same size despite contrary pilots comments. Indeed the second helmet was constructed with slightly more carbon fibre. This produces a much stronger shell which provides greater protection in the event of crash landing, although the shell may create the impression that it has a smaller size.

The **Centre of Gravity** (CG) of the two helmets is different. If the CG of the IHS is correct, the subjective impression of the two helmets being too small may diminish. Fig. 5 shows the CG of head, helmet and NBC–mask and the different torques, which act on the head. Also the centre of head motion and the origin of force of the extensor muscle is shown.The helmet should be designed that the total torque to the head keeps nearly constant with or without helmet. This is very important specially under high g–loads. But in reality the main optic parts are located on the front side of the helmet. Therefore parts, which don't have a fixed position like e.g. batteries, should be mounted on the back of the helmet as a balancing weight. For fixed wing aircrafts a **minimum of helmet weight** is the most important point of helmet design, no additional mass, which has only a balance function, is acceptable. Otherwise the pilot gets tired and unconcentrated under the strain of a high helmet mass after a short period. For helicopter application some of the german army pilots advocate the opinion that the correct centre of gravity is the main requirement. They would accept additional mass only with balance function.

Chin Cup: Originally the KNIGHT HELM was supplied with a leather padded neck strip. The pilots expressed concern that the neck strap was uncomfortable and did not aid helmet stability. The neckstrap was exchanged for a chin strap.

During the PAH 1 flight trials it became obvious that regardless of the parameters, the **exit pupil** is perhaps the most important consideration along with **weight**, **field of view** (FOV), **resolution** and **brightness gain**. A large exit pupil (greater than 13 mm) provides a very user friendly system, giving great confidence and comfort by knowing that there is a large night vision window to look through. If the IHS shall be moved, the pilot will not suddenly loose his vision of the outside and IIT image. A drawback of a large exit pupil is the increase of optical module weight.

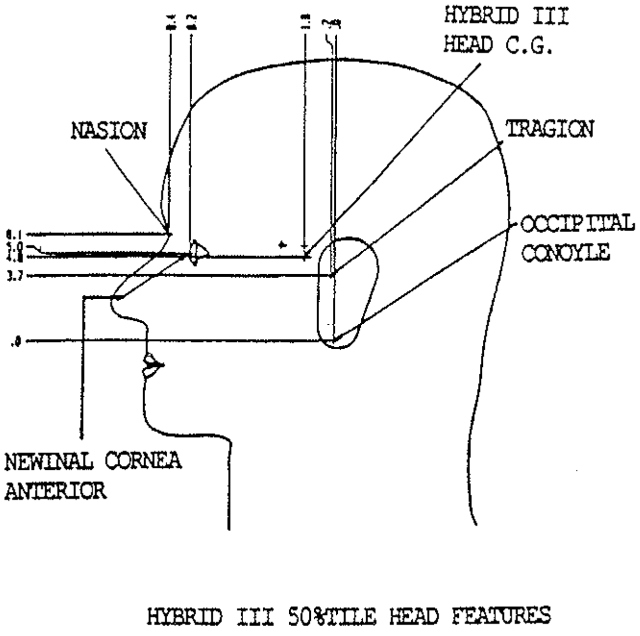


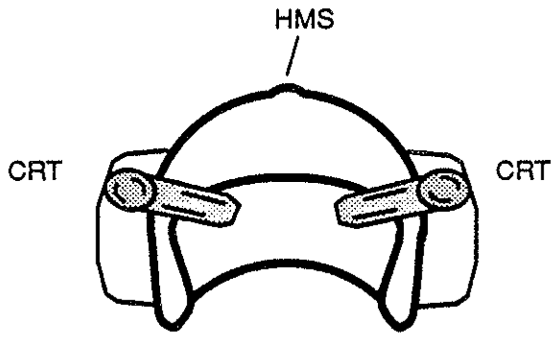
Fig. 5 Centre of gravity definition for human head (HYBRID III 50%tile head features, ref.9).

Other important parameters of a good IHS layout are:

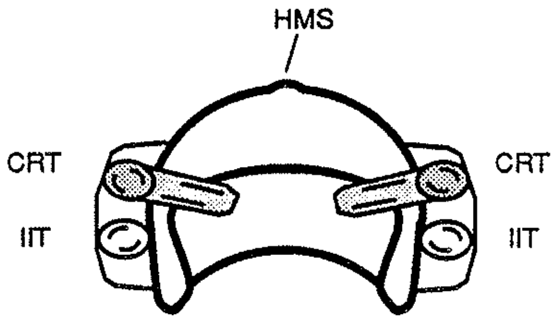
- **adjustment comfort** for:
  - inter pupillary distance, vertical, fore/aft/ tilt (eye relief)
    remark: personal adjustment on helmet;
  - divergence setting (stereo acuity), dipvergence tolerance, overlap, magnification 1:1
    remark: adjustment at supplier.
- good look around total field of regard (peripheral vision) with low obscuration of optical combiner edges, CRT– and IIT–FOV with 40° circular, magnification 1:1.
- crash protection
- Man Machine Interface (MMI): –wearing comfort, –usage of helmet, –cockpit workload, –Laser protection, –NBC–mask compatibility, –HID–compatibility, –cockpit illumination compatibility with IIT channel
- reliability and flight safety requirements: catastrophic fault should be zero
- speech / communication
- noise damping / active sound attenuation
- **easy modes / functions**
- fulfillment of **environment requirements** specially temperature, vibrations, EMC / NEMP
- **depth, motion** (optical flow) and **stereoscopic view perception**: biocular display gives a square root 2 advantages for two eyes in MCT (modulaton contrast thresholds), binocular IITs in an IHS have a base line of approx. 260 mm compared to approx. 60 mm IPD in NVG, remark: problems of distance estimation arises and new training is necessary compared to NVG HC flight, magnification problems! **Ivan Sutherland** has said, ref. 4, p. 82 and ref. 13: "Although stereo presentation is important to the **three–dimensional illusion**, it is less important than the change that takes place in the image when the observer **moves** his head. Psychologists have long known that moving perspective images appear strikingly three–dimensional even without stereo presentation".
- **quick release connector** with high tension safety, umbilical cable
- Boresighting Reticle Unit (BRU) in the cockpit with easy alignment functions

2.3 Comparison of the IHS–Design with a separate Day/Night or a combined Day/Night Module

2.3.1 Day Module and Night Module each separate



DAY MODULE



NIGHT MODULE

Fig. 6 Integrated Helmet with a separate day and night module

Advantages and disadvantages of a design with **separate day– and night– modules:**

Advantages:

- modules separate from basic helmet, each pilot has his own basic helmet (**personalized**), optical modules belong to HC
- min. weight on helmet for each **day/night** mission
- optimized transmission/brightness/contrast on **daytime** with 2 CRT only
- optimized transmission/brightness/contrast in the **night** with 2 CRT and 2 IIT

Drawbacks:

- **change** of modules necessary during **twilight**
- **storage** problems of modules in HC

2.3.2 One Day/Night Module

The principal design of an IHS with a combined Day/Night Module is shown in Fig. 7

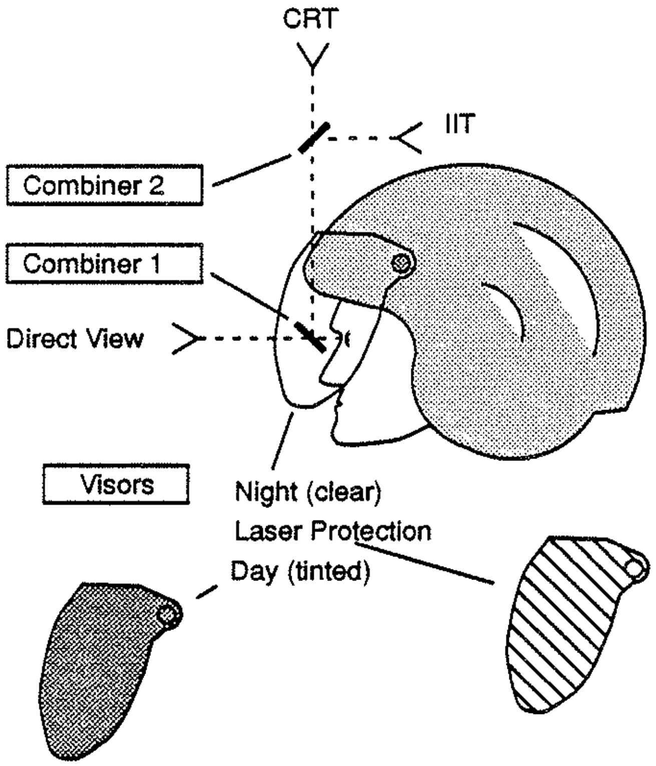


Fig. 7 Integrated Helmet with combined Day/night Module

Advantages and drawbacks of a **combined day– / night– module:**

Advantages:

- **no storage** problems in cockpit
- mission can be flown safely **without change of modules**
- minimal **parallax** between eye and night vision channel (IIT)

Drawbacks:

- **weight** of helmet higher than with separate modules
- **transmission** levels not optimized
- possibility that optical modules are fixed integrated in the helmet

⇒ Resume from GEC, ref. 5, p.92:

- It is possible to optimize a helmet display for DAY use.
- It is possible to optimize a helmet display for NIGHT use.
- But it is not possible to optimize **one helmet** display for both day and night use.

This configuration works very well in a night mission if the combiner has e.g. 70% transmission for IIT/CRT channel and a high IIT gain of approx. 5cd/sqm luminance level. However the drawback in daytime is that the combiner has an outside transmission of only 30%. This is to low for a cloudy/overcast day. To improve the day transmission for the CRT channel (brightness up to 34000cd/sqm) an optical or mechanical switch can solve the problem.

Fig. 8 shows the problem area of day/night transmission splitting.

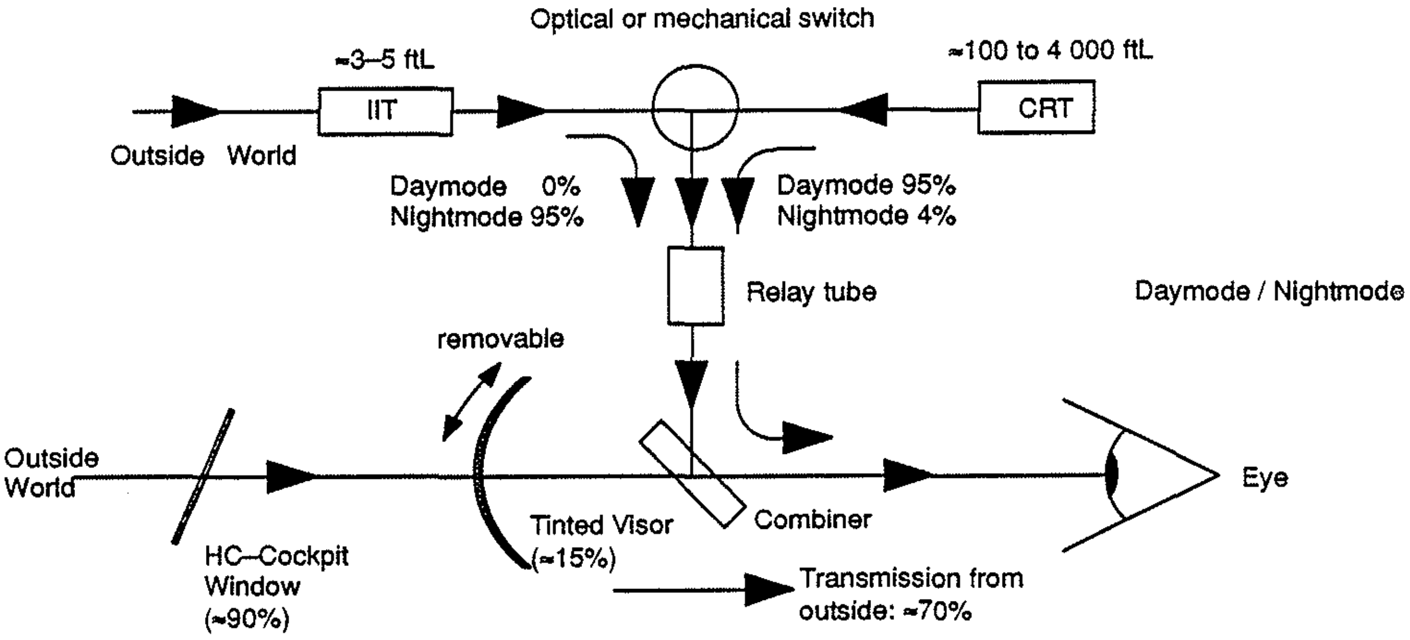


Fig. 8 Optical paths of a combined day/night module with optical or mechanical switch

2.4 Lab–Tests and HC–Trials with PAH 1 Demonstrator

The testing at the MBB laboratory was implemented for two state of the art Integrated Helmets, KNIGHT HELM and MONARC, compare fig.1 and 2. The test method for the optical IIT resolution measurement shows Fig. 9. The distance of the test target to the eye position is approx. 7m. The test pattern is a USAF 1951 target with approx. 70% contrast.

During extensive flight trials (May 90 to Jan. 91) the German Army compared the established Philips Night Vision Goggles (NVG) 3rd generation tubes with the KNIGHT HELM. In the landscape of Northern Germany, the lighting conditions under which the goggles must perform can vary over almost four decades, from 0.1 mLux to almost 500 mLux, presenting any NVG with a very severe task. The German Army is expected to fly in a particularly stringent combination of circumstances: overcast starlight, mist and precipitation at very low altitude, two or three meters above ground level between areas with obstacles. The ambient light available may be only 0.3 mLux or below. The experience shows that there is no substitute for flight trials, e.g. lab and simulator tests only, to completely understand an IHS.

The **Philips NVG** is the benchmark of the IHSs:

The Philips NVG comprises two identical straight through monoculars with fixed objective focus (approx. 10m to infinity) and adjustable eyepiece focus. The objective is a 26 mm focal length, F–No.1.2 lens with a circular field of 42° and a magnification of 1:1. The two monoculars are held together at the front on a tilting hinge for adjustment of IPD at the rear. Adjustment of IPD will vary the FOV overlap. A torch lamp is attached to the front of the binocular channels and operates by a lip switch to illuminate the cockpit, ref. 12. The resolution measurement will be shown in the next chapter 2.5.

The main results of IHS including problem areas will be discussed in the next chapters.

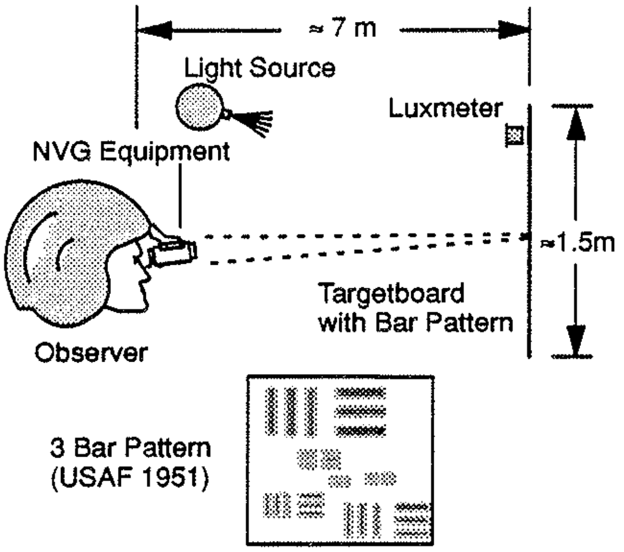


Fig. 9 Top View of the Test Set to measure the Resolution and Sensitivity of NVG's and Integrated Night Vision Helmets as a function of illumination level.

2.5 Image Intensifier Tube – Testing

Tests were carried out at MBB on the optical performance of the IITs: **Philips 3rd gen. NVG, KNIGHT HELM** and **MONARC.** The left hand and right hand IITs were tested together with a two alternative forced choice (2AFC) method to determine resolution. Additionally the USAF 1951 test pattern was used. The objective lenses were focussed correctly with the 7m object distance. A fixed color temperature light source from an integrated sphere was available. The illumination levels were measured at the IHS and in the target plane. The results are shown in fig. 10.

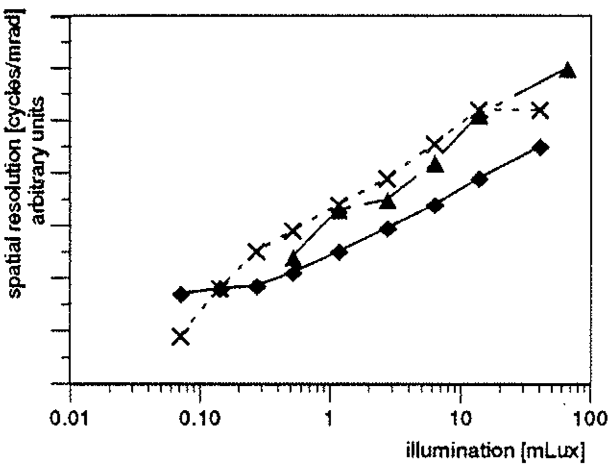


Fig. 10 Resolution tests for 3.Gen. NVG FOV 42° circ.(♦—♦), KNIGHT HELM FOV 35° circ. (▲- · ▲) and MONARC FOV 35° circ. (x···x)

Other important parameters of a good IIT layout are:

- good brightness at low background illumination (LBI) is necessary
- Automatic Gain Control (AGC) lies between 1500 and 2900 at 10^{-2} cd/sqm
- **daylight filters** (neutral filters) for training purpose are desirable with attenuation of 10^{-7} and 10^{-9}
- 645 nm **cut off filters** with antifluorescent coating were used
- **image quality**: snow/scintillations (S/N) and homogeneity over combiner must be good
- **tube life time**, (InSb sealing!), temperature range with full performance between –12° C and 42° C

2.6 CRT–Testing

A 1" tube has a 25mm diameter faceplate with a screen diameter of 19mm. The spot (pixel) size is approx. 18µm at 200ftL or 25µm at 500ftL for P43 Phosphore (gaussian profile). If one considers a future requirement for a high luminance (approx. 10 000ftL) allowing daylight raster viewability then this will require at the present time a further sacrifice in resolution with a low drive value of 24µm and a high drive value of 32µm.

Other parameters of a CRT are:

- **high brightness** necessary for day flight with symbology, same brightness of the two images
- 10 grey levels with relative good brightness and contrast
- **high resolution** image, approx. 18µm spot size or approx. 40 Lp/mm with good quality/homogeneity/min.distortion, same for both CRTs
- high brightness (approx. 4 000 ftL) with poor resolution and reduced grey levels.
- **no vignetting** of image edges, low distorsion
- ghost image (double image) should be zero; coating problems at IIT/CRT–beamsplitter (reflections)
- fast Stroke (cursive) symbols written in Raster flyback / Raster display of sensor video possibility
- **head roll compensation** necessary
- optimized overlap, divergence and dipvergence of the two channels
- raster scan generator shows 0.8 cycle/mrad for KNIGHT HELM and MONARC
- circular test pattern shows low distortion,
- electronic distortion compensation necessary
- **high voltage isolation**

2.7 Nose or Helmet Solution for a Second Night Vision Sensor

2.7.1 General remarks to IIT–CCD sensors for use as Nose Solution

The IIT image is converted with a CCD (Charged Coupled Device) to video standard and displayed with a CRT to the eye. The alignment of IIT and TI channel is much easier.. Electronic image processing for image fusion can be used as growth potential.

A strong drawback is the dependence of power for both channels. If HC power fails no redundancy will exist. The flight safety/reliability decreases with this arrangement.

2.7.2 Second Sensor Installation Comparison between HC Nose Solution and Helmet Solution

There are two possibilities to install the IIT sensor:

- o nose solution with IIT–CCD and TI sensors, fig. 11 .
- o helmet solution with IIT sensors on helmet, TI sensor on HC nose, fig. 12.

The TI/IIT–CCD sensors are located in the HC nose below the pilots design eye point steered by HMS. This can produce problems of parallax, wrong depth perception and apparent motion. However if the IIT channels are helmet mounted, there exist problems with switching of two different visual reference points.

Aspects of the Nose Solution:

operational advantages:

- free of parallax between sensors on platform, but not between sensor and eye (with direct view)
- video signal of IIT–CCD and TI available, image processing (sensor fusion) is possible
- sensors optimized for day–, twilight– and night – conditions without changing of any optical modules
- lower weight on helmet

operational disadvantages:

- platform slaving error in relation to the head Line of Sight (LOS)
- additional equipment has to be mounted on an existing platform
- less redundancy than the case with IIT only, degraded flight safety

economic and program aspects:

- higher costs compared to helmet solution if an existing system shall be retrofitted

Aspects of the Helmet Solution:

operational advantages:

- natural use of the visual aids
- no slaving error
- no parallax between eye and IIT
- installation easier
- high redundancy
- high reliability
- high flight security
- easy hardware update
- less aircraft weight

operational disadvantages:

- 2 optical modules necessary (for day and night)
- parallax between TI and IIT
- additional weight on helmet
- image processing not possible
- greater helmet complexity

economic and program aspects:

- lower costs compared to nose if a retrofit of an existing system should be realized
- possible solution for different types of helicopters

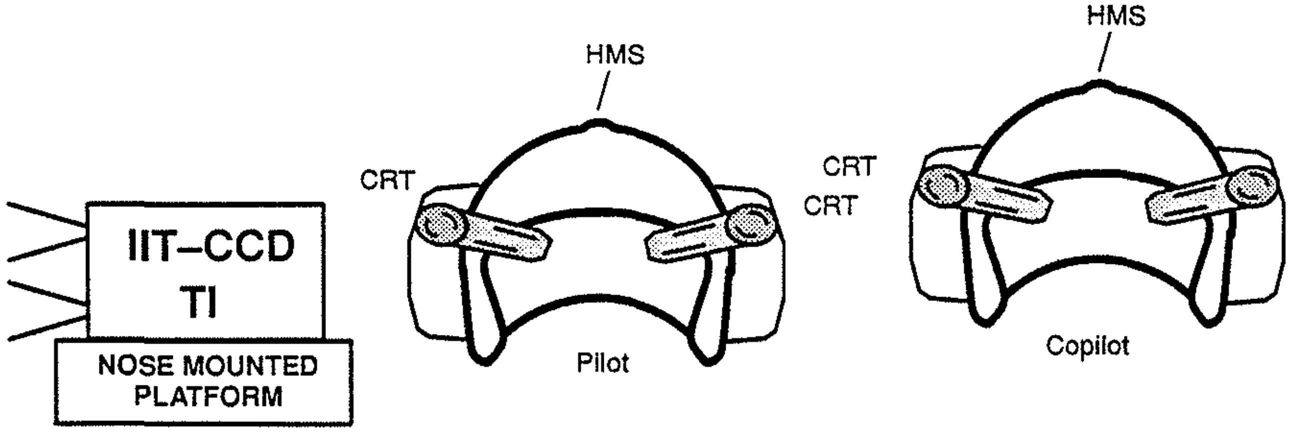


Fig. 11 **Nose solution** with IIT–CCD and IHS has only 2 CRTs.

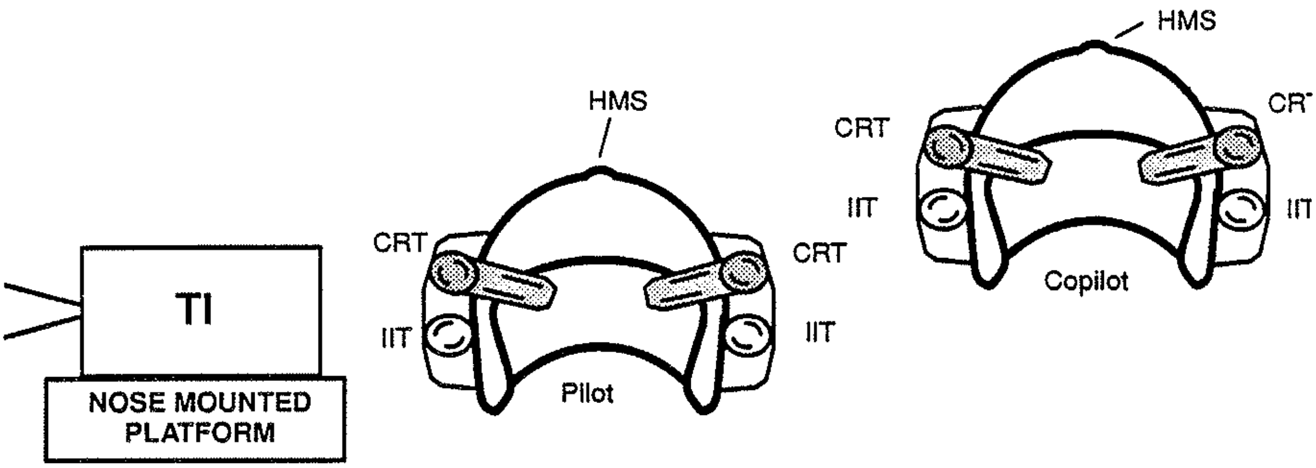


Fig. 12 **Helmet Solution** with 2 CRT and 2 IIT sensors.

3. HELMET MOUNTED SIGHT SYSTEMS

3.1 Principles of HMS – Systems

The purpose of the HMS is to steer either a platform with optical sensors, a landing light platform or a weapon platform in accordance with the head motion of e.g. a helicopter crew. Fig. 13 shows the silhouettes from TIGER–HC from the side. The measured values of the head motion angles must be of high accuracy and to be available with a minimum of time delay.

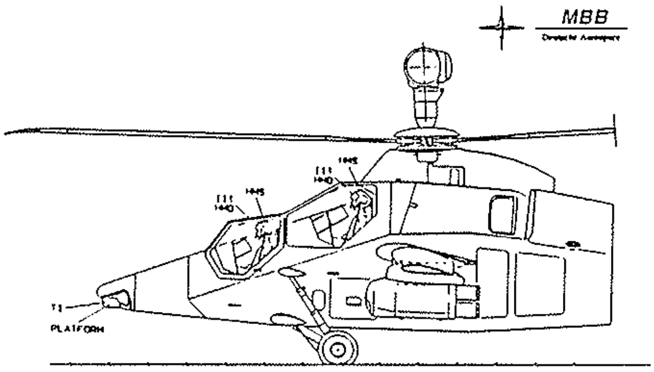


Fig. 13 PAH 2 with steerable platform and HMS–system

The helmet mounted sight systems can be realized using different physical principles. In the following the important HMSs of today are described with their main characteristics:

AC–Electromagnetic Systems (e.g. Polhemus, Ferranti, Sextant)

- based on alternating electromagnetic waves
- transmitter (3 orthogonal coils) mounted in HC–cockpit
- receiver (3 orthogonal coils) mounted on the helmet
- calculating head direction inside the Head Motion Box (HMB) according the induced voltages
- disturbances whilst changing metal surrounding
- cockpit mapping necessary

DC–Electromagnetic Systems (e.g. GEC Avionics)

- based on quasi–constant electromagnetic field
- transmitter (3 orthogonal coils) mounted in HC–cockpit
- receiver (3 orthogonal coils) mounted on the helmet
- receiver is working like a magnetometer
- DC–systems are less sensitive to metals as AC–systems

Electro Acoustic Systems (e.g. TST)

- based on ultrasonic waves
- transmitter (e.g. 6 pieces) mounted on the helmet
- receiver (e.g. 6 pieces) mounted in HC–cockpit
- head direction is calculated according the propagation time of ultrasonic waves
- pulse code modulation prevents disturbances from any ultrasonic noise
- disturbances due to rapid changes of dispersion medium air are possible, the influence of normal cockpit airflow is compensated

Pattern Recognition systems (e.g. ELOP)

- receiver is a CCD camera mounted in the HC–cockpit

- transmitter is a geometric pattern which is painted on the helmet or a pattern of LEDs which is mounted on the helmet
- head direction is calculated with the aid of image processing of the video image of the pattern on the helmet
- disturbances whilst sensor saturation due to direct sun light illumination
- problems in detecting the geometric pattern during night

Electro Optical Systems (e.g. Honeywell, IHADSS)

- transmitters are special units, mounted in the HC–cockpit, emitting pulsed IR–radiation
- receivers are two IR–detector sets mounted on each side of the helmet
- problems may occur if direct sunlight disturbs the detectors

3.2 Test Procedures

3.2.1 Error Definition

An important point for understanding and comparison of tracker errors is an exact definition of the errors.

In Fig. 14 we have plotted the error definition. The diagram shows the statistics of measurements of a common value. Plotted on the y–axis is the occurrence of the feed back value of the measurements. There is a distribution of the values around a maximum of occurrence.

The maximum error is calculated by the difference between command value and feed back value plus the reproducibility of the feed back value. This maximum error has two different error types: the **systematic error** and the **statistic error.**

Systematic error:

The deviation between **command value** and measured **feed back** value depends on the command value. It can not be given as a general function, because the dependence is specific to the HMS–alignment. This is a systematic error. If the measurement system is well known and has a good reproducibility this error could be corrected. In case of a HMS–system this will be done by cockpit–mapping and after full system development the systematic error should be nearly zero.

Statistic error:

The most important error value is the reproducibility (σ). This value determines the minimal approachable system accuracy. The tolerance values can be defined in σ – or standard deviation (SD) values. Chapter 3.3.2 describes also the circular error probability (CEP) for σ_x (AZ) and σ_y (EL).

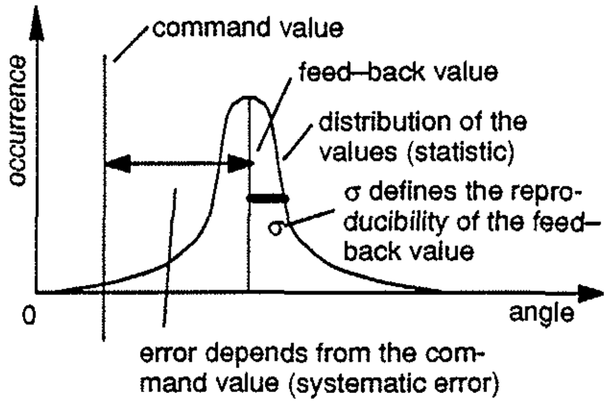


Fig. 14 Error Definition

3.2.2 Test Equipment

In fig. 15 the principle setup of the MBB accuracy test rig is shown. The basis of the rig are two metal plates. Three mounting screws allow a vertical adjustment and a tilting of the plates together. On the upper plate the stepper motor for the azimuth movement is fixed. The whole helmet fixture is mounted on this motor. Additionally an angular steel support is fixed to mount a second stepper motor with vertical axis. This motor is connected with a mechanical linkage which allows the movement of the helmet in elevation.

One requirement to the test rig is the use of non–metallic materials above the stepper motors to be able to test HMS–systems on electromagnetic basis. Metallic influences of the test rig itself cannot be accepted during testing.

The movement of the helmet in azimuth and elevation is **fully automated and computer controlled.** The command values can be given from a PC. A **special software** converts the angle values to motor steps and controls movement, velocity and acceleration of the motors. The maximal resolution of the stepper motors is 0.01° at a maximal velocity of 100°/s. The helmet movement in roll can be done manually in steps of 15°.

The maximal angle range of the helmet movement is limited by the mechanics of the test rig to:

- azimuth +/–180°
- elevation +25°, –30°
- roll +/– 45°.

The accuracy of the MBB testrig has been tested and has the values of:

- 0.01° in azimuth and
- 0.05° in elevation.

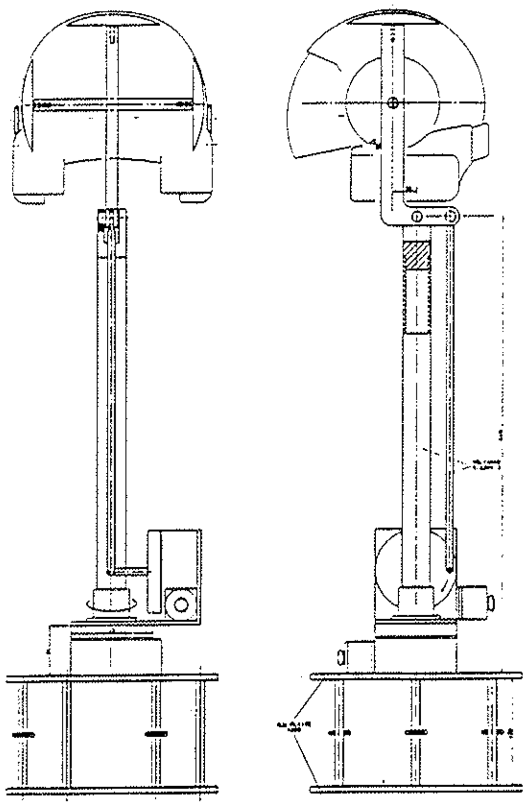


Fig. 15 MBB Test Rig for Helmet Mounted Tracker Evaluation

Installation of the test rig in the helicopter (Fig.16):

- A wooden table which can be adjusted vertically is mounted over the pilot's seat.
- The helmet including the transmitter respectively receiver is mounted to the test rig.
- The test rig is fixed with screws on the wooden table. The test rig may be adjusted in height as well as in tilt to the helicopter frame.

3.2.3 Test Program

We have divided the test program into two parts, **static measurements** and **dynamic measurements.**

3.2.3.1 Static Measurements

The HMB is defined as the movement area of the pilots head. Inside this HMB the specified accuracy of the HMS–system has to be verified. The dimensions of the HMB vary from helicopter to helicopter, for an example Fig. 17 shows a HMB of 400mm x 400mm x 200mm with selected measurement points.

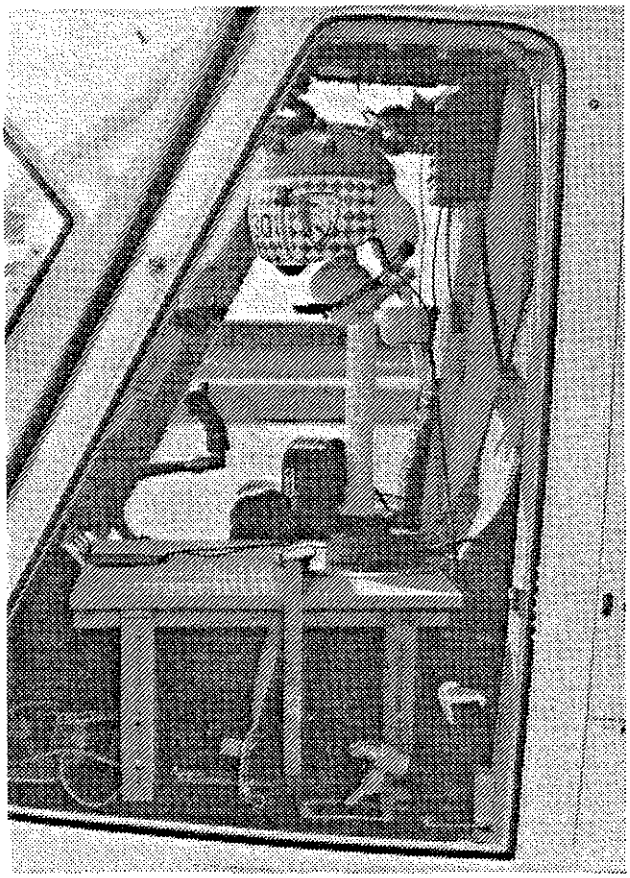


Fig. 16 Test Rig with Helmet and HMS in a BK 117 helicopter (TST – electro acoustic system)

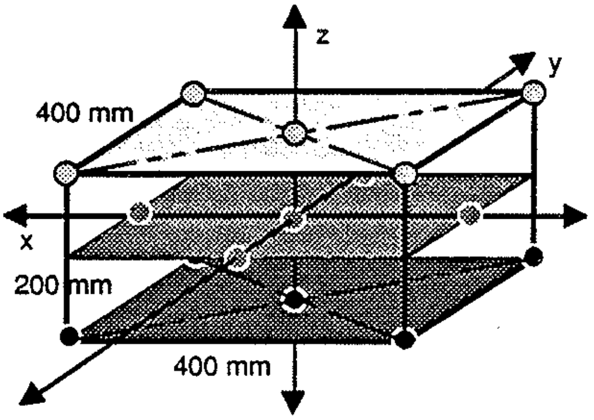


Fig. 17 Testing Positions inside the Head Motion Box

In the static part we have measured the accuracy of the HMS–system in the centre of the HMB with an enhanced set of angles:

elevation angles of 0°, +20°, –20° in combination with the azimuth angles:
0°, +/–5°, +/–10°, +/–15°, +/–20°, +/–25°, +/–30°, +/–45°, +/–60°, +/–75°, +/–90°,
and roll angle 0°

and the elevation angles of +10°, −10° in combination with the azimuth angles:
0°, +/−15°, +/−30°, +/−45°, +/−60°, +/−90°

Test procedure in the centre of HMB:

- Boresighting of the HMS–system.
- For one fixed elevation angle the complete set of azimuth angles will be commanded step by step and for each point the HMS angle measurement values for azimuth, elevation and roll will be noted.
- This set of azimuth angles with the fixed elevation value will be measured for several (e.g. 10) times. Out of these values we calculate the maximum of the absolute error and the reproducibility (standard deviation).
- The above mentioned measurement has been repeated with all elevation angles.

Measurements of different roll angles are carried out in steps of 15° with azimuth = elevation = 0°.

In the all other points of the HMB (compare Fig. 17) a reduced set of measurement was carried out with elevation angles of 0°, +/− 20° in combination with azimuth angles : 0°, +/− 15°, +/−30°, +/− 60°, +/− 90°.

3.2.3.2 Dynamic Measurements

Dynamic measurements are necessary to ensure that the delay between head movement and the electrical output is in an acceptable frame. Long delays decrease the flight safety if e.g. a steerable FLIR is used for piloting.

For verifying the delay the test rig including the helmet carries out periodic movements in azimuth. For this movement the stepper motors of the test rig may realize a maximum velocity of 100° per second. In the computer protocol the output values can be compared with the stimuli and may be checked for achievement of the maximum values and the maximum velocity at the zero point.

3.3 Test Evaluation of an Electro Acoustic HMS–System from TST (Telefunken System Technik)

3.3.1 Static measurements

Calculation of mean values, standard deviation (n−1) and the absolute errors (command– minus feed–back values) according to the above mentioned test plan. As result we get the absolute errors as well as the reproducibility of **azimuth** (fig. 18), **elevation** and **roll**.

The result of a complete measurement are about **100 of these diagrams**. For an overview of the accuracy a data reduction has to be implemented!

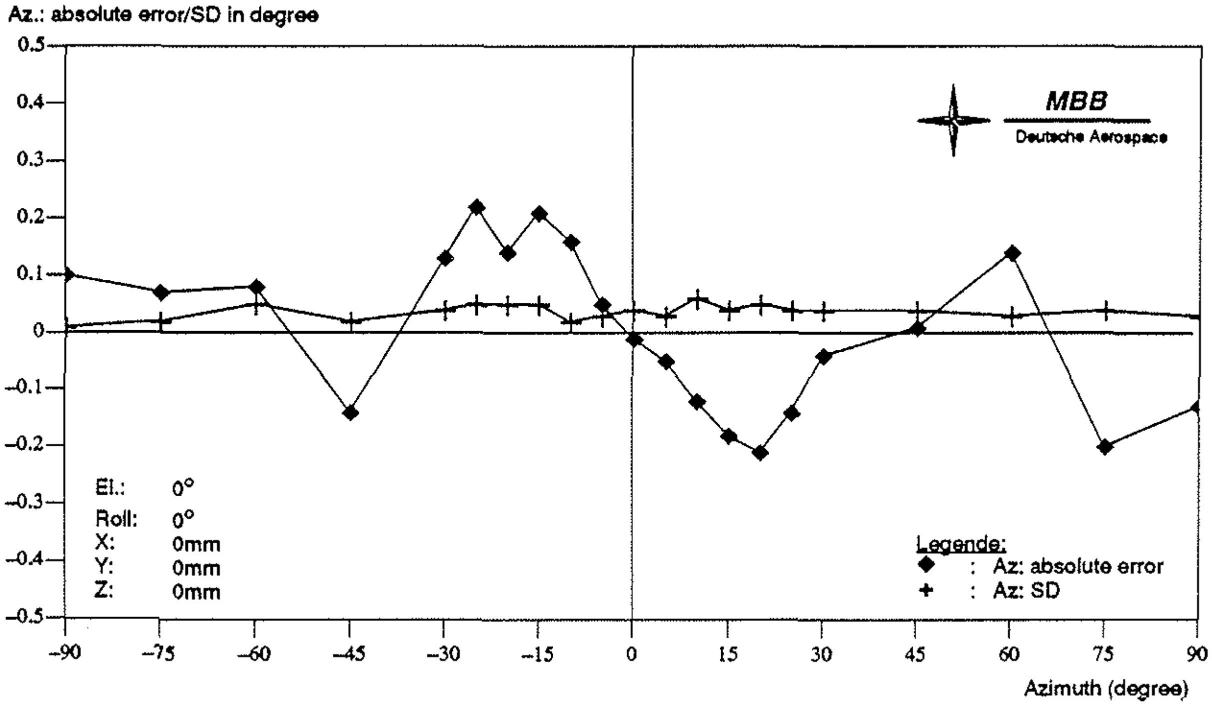


Fig. 18 Absolute error of and standard deviation of azimuth as a function of the azimuth angle (electro–acoustic system).

3.3.2 Data Reduction

Calculations of the mean value of the absolute errors and the mean value of the SD for all angles (separately done for azimuth, elevation and roll), which were measured during one scan of azimuth with constant elevation angle are shown in fig. 19. The maximum and the minimum values are also mentioned to see the bandwidth of the error. Additionally the circular error probability (99.9% probability) $CEP_{0.999}$ is calculated. The approximation formula for $CEP_{0.999}$ is (ref. 15.)

$$CEP_{0.999} = \sigma_y(3.408 - 0.643\rho + 0.923\sigma^2)$$

with $\rho = \sigma_x/\sigma_y$ and $\sigma_y > \sigma_x$.

This procedure is done for each measurement point.

MBB Deutsche Aerospace		AZIMUTH (°)			ELEVATION (°)			CEP 99.9% (°)		
El. angle		min.	mean	max.	min.	mean	max.	min.	mean	max.
0°	abs. error	0.01	0.12	0.22	0.02	0.25	0.86			
	SD	0.01	0.04	0.06	0.01	0.03	0.05	0.037	0.14	0.21
+10°	abs. error	0.09	0.24	0.50	0.04	0.36	1.08			
	SD	0.01	0.03	0.05	0.01	0.02	0.03	0.037	0.10	0.17
–10°	abs. error	0.01	0.29	0.54	0.01	0.35	0.72			
	SD	0.01	0.03	0.04	0.02	0.02	0.05	0.058	0.10	0.17
+20°	abs. error	0.01	0.58	1.26	0.00	0.33	1.16			
	SD	0.01	0.04	0.07	0.02	0.03	0.06	0.066	0.14	0.25
–20°	abs. error	0.01	0.45	0.70	0.00	0.37	0.77			
	SD	0.02	0.04	0.06	0.01	0.03	0.07	0.066	0.14	0.25

Fig. 19 Mean value of the absolute errors and the mean value of the standard deviations for all **azimuth and elevation angle values**, which were measured during one scan of azimuth with constant elevation angle (electro acoustic system). The 99.9% **circular probability** is calculated in the third column.

Fig. 20 shows the azimuth and elevation SD mean values over all measured azimuth angles (with constant elevation angle) and the $CEP_{0.999}$ as a function of the **elevation angle** for one point inside the HMB.

Fig. 21 shows azimuth, elevation and roll mean values of the absolute error and the SD (calculated like the values in fig. 19 for the elevation angle 0°) for different points inside the HMB. Fig. 22 is a diagram in which the mean values of the absolute errors in azimuth, elevation and roll are plotted as a **function of one dimension of the HMB.**

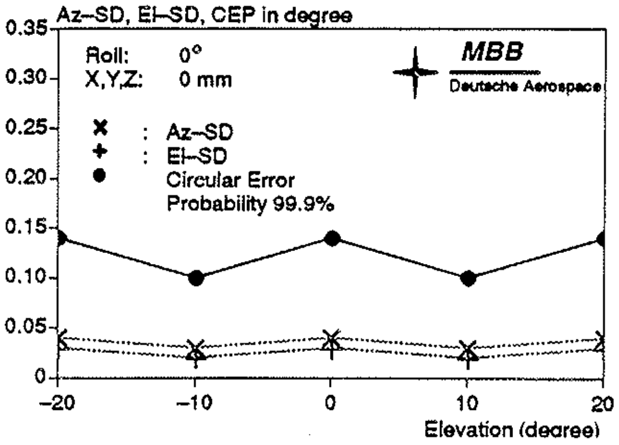


Fig. 20 Azimuth and elevation mean values of the standard deviation over all measured azimuth angles (with constant elevation angle) and the 99.9% circular probability as a function of the elevation angle for one point inside the HMB (electro acoustic system).

		HMB – Position		
		X= –100 / Y,Z = 0	X, Y, Z = 0	X = +100 / Y, Z = 0
Mean value of absolute error	Az. El. Ro.	0.15° 0.34° 0.29°	0.12° 0.25° 0.27°	0.09° 0.33° 0.42°
Mean value of SD	Az. El. Ro.	0.02° 0.02° 0.02°	0.04° 0.03° 0.03°	0.02° 0.02° 0.02°

Fig. 21 Mean values of absolute errors and SD for azimuth, elevation and roll for different HMB – Positions.

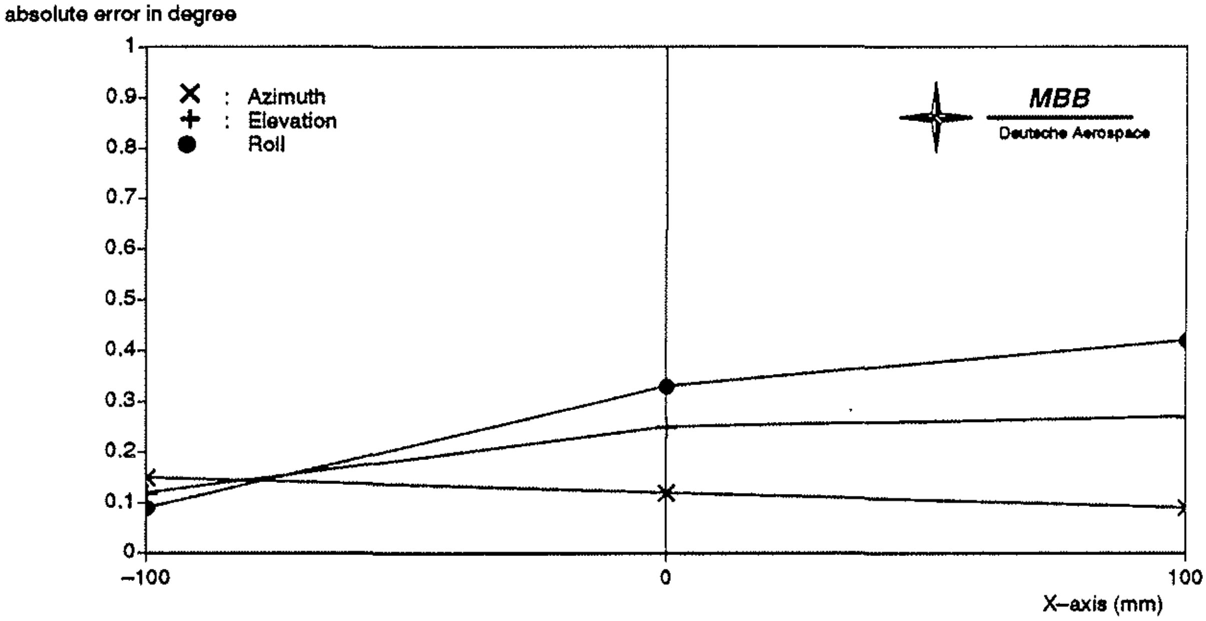


Fig. 22 Mean values of absolute errors for azimuth, elevation and roll as a function of one dimension of the HMB (electro acoustic system).

3.3.3 Dynamic Measurements

For the dynamic measurements we have connected the HMS measurement values of the azimuth angle to an x–t recorder, while the helmet on the testrig carries out periodic movements. In fig. 23 achievement of maximal angles can be checked. Additional the HMS output for the maximal velocity of the movement (calculated according the slope of the curve) can be compared with the commanded motor velocity.

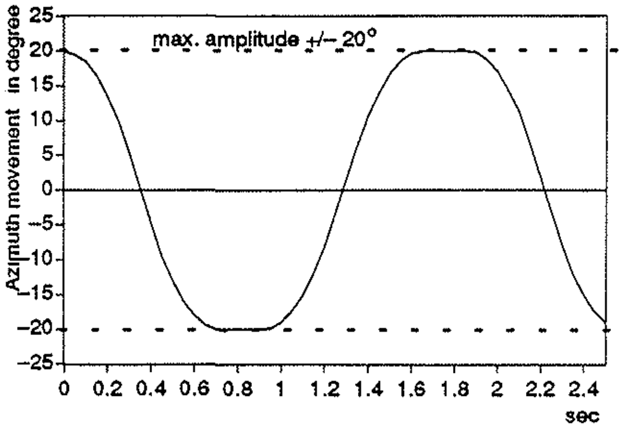


Fig. 23 Time Plot of the dynamic measurements (electro acoustic system), max. test rig velocity is 100°/s.

3.4 Test Evaluation of a DC Electro Magnetic HMS–System from GEC Avionics

3.4.1 Static measurements

Explanations see chapter 3.3.1.

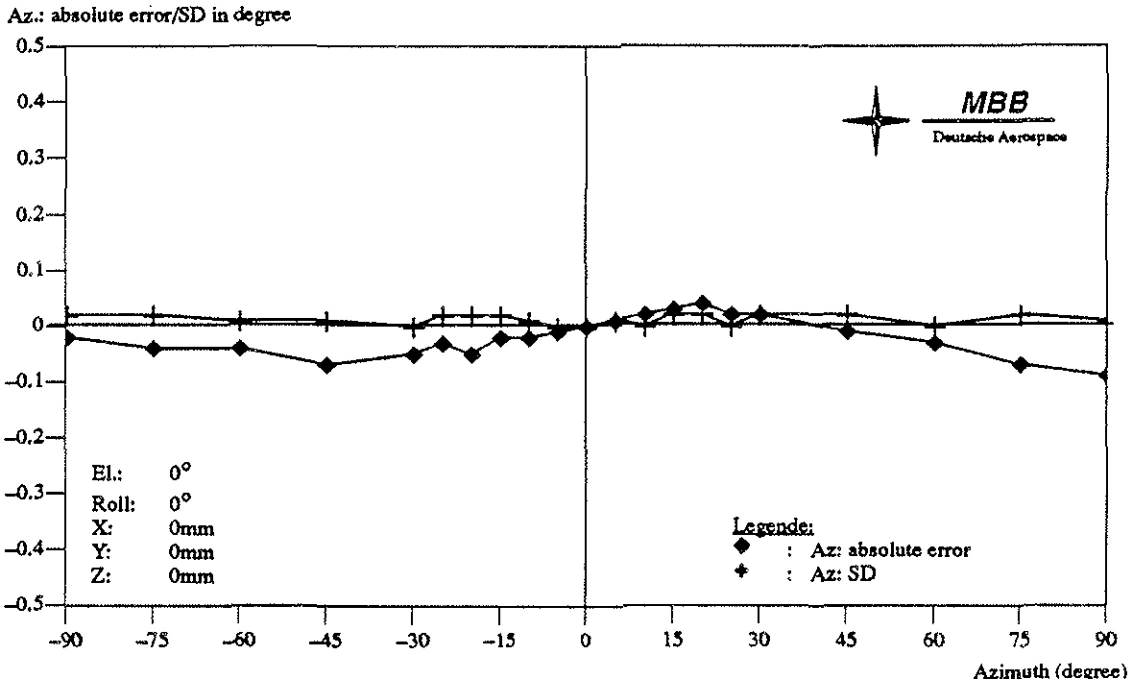


Fig. 24 Absolute error of azimuth and standard deviation as a function of the azimuth angle (DC–EM system).

3.4.2 Data Reduction

Explanations see chapter 3.3.2.

		AZIMUTH (°)			ELEVATION (°)			CEP 99.9% (°)		
El. angle		min.	mean	max.	min.	mean	max.	min.	mean	max.
0°	abs. error	0.00	0.03	0.09	0.01	0.10	0.26			
	SD	0.00	0.01	0.02	0.01	0.03	0.04	0.034	0.099	0.13
+10°	abs. error	0.11	0.17	0.21	0.12	0.46	0.61			
	SD	0.00	0.02	0.02	0.02	0.03	0.05	0.068	0.10	0.16
–10°	abs. error	0.00	0.07	0.15	0.07	0.15	0.21			
	SD	0.00	0.01	0.02	0.00	0.02	0.04	0.0	0.066	0.13
+20°	abs. error	0.02	0.19	0.37	0.41	0.58	0.68			
	SD	0.00	0.04	0.07	0.00	0.04	0.11	0.0	0.15	0.37
–20°	abs. error	0.00	0.17	0.57	0.00	0.10	0.16			
	SD	0.00	0.04	0.12	0.02	0.10	0.26	0.068	0.33	0.86

Fig. 25 Mean value of the absolute errors and the mean value of the standard deviations for all **azimuth and elevation angle values**, which were measured during one scan of azimuth with constant elevation angle (DC electro magnetic system). The 99.9% **circular probability** is calculated in the third column.

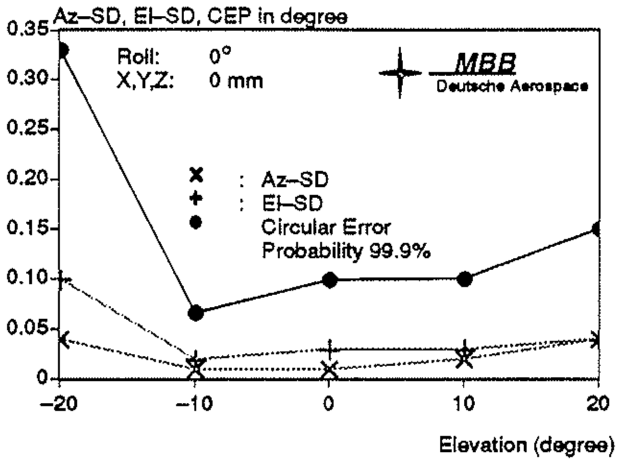


Fig. 26 Azimuth and elevation mean values of the standard deviations over all measured azimuth angles (with constant elevation angle) and the 99.9% circular probability as a function of the elevation angle for one point inside the HMB (DC electro mgnetic system).

		HMB – Position		
		X= –200 / Y,Z = 0	X, Y, Z = 0	X = +200 / Y, Z = 0
Mean value of absolute error	Az.	0.08°	0.03°	0.11°
	El.	0.22°	0.10°	0.14°
	Ro.	0.30°	0.14°	0.21°
Mean value of SD	Az.	0.01°	0.01°	0.02°
	El.	0.02°	0.03°	0.04°
	Ro.	0.02°	0.03°	0.04°

Fig. 27 Mean values of absolute errors and general SD for azimuth, elevation and roll for different HMB–Positions.

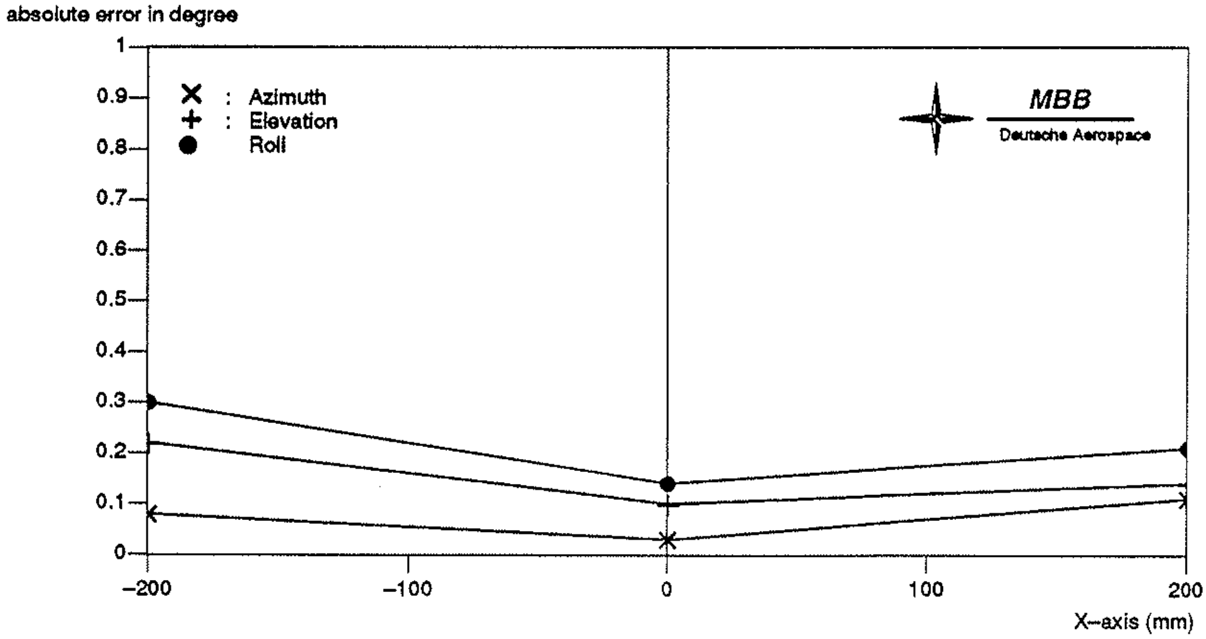


Fig. 28 Mean value and standard deviation of all measured azimuth angle values (with constant elevation angle = 0°) as a function of one dimension of the head motion box (DC–EM system).

3.4.3 Dynamic Measurements

Explanations see chapter 3.3.3.

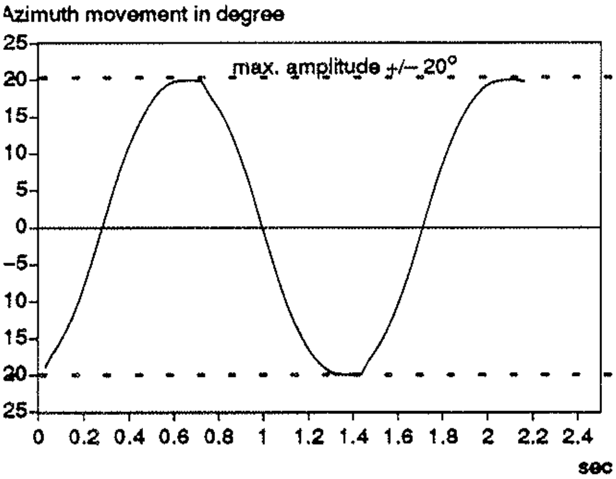


Fig. 29 Time Plot of the dynamic measurements (DC–EM system), max. test rig velocity is 100°/s.

3.5 Additional Measurements

The following additional measurements have been included in our measurements:

- controlling the longtime stability of the electronics (2h)
- qualitative disturbance measurements, especially for the tested HMS, e.g.:
  - AC–, DC–systems: additional metal parts between transmitter and receiver
  - DC–systems: influence of the magnetic earthfield
  - Electro Acoustic systems: switching on the helicopter ventilation, thermal changes in the cockpit, as e.g. direct sunlight
  - Optical systems: sensor saturation due to e.g. direct sun illumination
- influence of running engines and rotors:
  - electric disturbances
  - acoustic disturbances
  - helicopter vibrations

4. CONCLUSION

The helicopter flight trials and laboratory tests are carried out to gather experience of operation with state of the art IHS equipment before deciding on the final configuration. The extensive trials showed that there is no substitute for flight trials, e.g. laboratory and simulator tests only, to completely understand an IHS for day and night flight capability. The difficult human engineering aspects have to be evaluated with functional IHS models to find the necessary improvements.

The work of this paper is partly a result from a HMS measurement campaign on BK 117, visionic lab tests and troop flight trials with PAH 1. These programmes were launched by "Bundesamt für Wehrtechnik und Beschaffung" (BWB) and "Bundes Ministerium für Verteidigung" (BMVg, German Ministry of Defence).

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